THE GEOLOGY AND PETROLOGY OF THE GREAT SERPENTINE BELT OF NEW SOUTH WALES.

Part ii. The Geology of the Nundle District.

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(Plates xxii.-xxiv.)

The Nundle District lies near the head of the Peel River, the chief township being 37 miles from Tamworth. Gold was discovered here in 1852, and mining has been carried on fitfully ever since. The district is divided diagonally by the Peel River, to the east of which lie the high outposts of the New England Plateau, with the lesser heights of the Peel River Buttress to the west. Nundle lies in the hollow produced by down-faulting. The smaller township of Bowling Alley Point is in the narrow valley of the river, by which it leaves this sunken area, while the rapidly growing, agricultural township of Woolomin lies on the wide-spreading, alluvial flats at the junction of the Peel River and Duncan's Creek.

The amount of detailed work done here, previously, is very small, the reports of Clarke(3), Odernheimer(5), Wilkinson(25), and Jaquet(4) being the only important writings, and the two latter are concerned chiefly with the Tertiary drifts. No systematic survey has yet been attempted. The map given (Plate xxii.) may, therefore, claim to be original in every detail. A preliminary account of this area was read two years ago(15), but subsequent work has called for some modification in the conclusions then reached, and a much more detailed map is here presented.

The Palæozoic foundation rocks fall into three series, the Woolomin Series, the Bowling Alley Series, and the Nundle Series. The first occupies the eastern side of the area, and is

separated by the line of peridotite-intrusions from the Bowling Alley Series. The latter passes directly upwards into the Nundle Series without any unconformity. It has been shown (see Part i.) that these three Series exist throughout the whole belt as far as Warialda, that the Bowling Alley belts are the local equivalent of the Tamworth Series, that the Nundle Series corresponds to the Barraba Series, and that reasons may be offered for the absence of the Baldwin Agglomerates. The higher Burindi Series does not appear till one reaches Goonoo Goonoo, 20 miles to the west.

We now proceed to a detailed description of the several formations, as developed in this area.

(1). Woolomin Series.

The eastern portion of the area is made up of rocks of the Woolomin Series. Their western boundary is the line of fault, which is marked throughout by the serpentine-intrusions. The series is made up of jaspers, phyllites, spilite-lavas, and tuffs, with occasionally conglomerates. The jaspers are the most striking rocks, and are developed in long bands not quite parallel to the serpentine-line. Commencing in the rugged cliffs of Wallaby Mountain, west of Woolomin, they may be followed across the Peel River; they form the Peak by Warden's Farm, and the high rocks overlooking Sheep Station Creek; and then continue along the line of watershed between Munro's and Duncan's Creeks, and finally are cut out by the granodiorite. A line of section from Warden's Farm, on the Peel River, across to Duncan's Creek, shows nine bands of jasper, varying in width up to 100 feet, and invariably giving marked relief. They are not banded but homogeneous, pale pink to deep red in colour, and with traces of radiolaria, which are rarely visible distinctly in microscopic section. They are often intensely silicified, riddled with twisting quartz-veins, small or reaching some yards in width, and, in one instance, the jasper-band is entirely replaced by a huge white quartz-reef, over 100 yards long, and 8 or 10 yards wide, that stands out, like a wall, from the eastward-facing cliffs beyond the head of Munro's Creek, and is protecting the upper

waters of that creek from capture by the Duncan's Creek System. On the other hand, the ferruginous content of the jasper may increase till the rock becomes merely a siliceous hæmatite. This, however, is unusual. Very ferruginous phyllite is more common, and passages from this into a jasperoid rock are frequently observable.

Between the jaspers, are normal micaceous phyllites and varying types of green and purple schistose tuff that have not as yet been much investigated. Spilites are common in varying stages of alteration. In the field, before microscopic investigation had shown their nature, they were a great puzzle, and were considered to be a dark-coloured hornfels. They are all fine-grained, often slightly vesicular, and break with difficulty, giving an irregular fracture. They are much sheared and jointed, and, in some forms of alteration, strongly resemble altered mudstone. They have been found in various localities, and are particularly abundant on the slopes east of Munro's Creek, where they are invaded by the porphyries. Here they are probably the predominant rock, and are, no doubt, far more abundant elsewhere than is at present known.

Between the head of Munro's Creek and Swamp Creek, there is a wedge-shaped area of Woolomin rocks differing from those described above, but resembling what may be found near Mundowey, on the Namoi River. This area has not been much investigated, and is doubly difficult of study owing to its poverty in good outcrops, and the thickness of the vegetation. A peculiar slatey conglomerate forms the northern portion, and stretches from north of Folly Creek down to Nuggety Creek, along its western tributary; while hence, to the south and east, a tough, grey, non-schistose hornstone is present, suggesting an altered microcrystalline rock porphyritic in quartz, but which, on microscopic examination, is clearly clastic. A similar rock occurs at Mundowey. A little inlier of this rock is to be found among the basalts near the head of Swamp Creek (here called Burrows' Creek). It is quite impossible, so far, to make any statement of the stratigraphy of this much disturbed area. Many of the dips recorded are probably only cleavage-plane slopes, but wherever

the true dip is seen, like the cleavage-plane, it has a general strike of N.20°W., and a dip varying from the vertical to 70° to the east, or occasionally to the west. In the Swamp Oak district, some fifteen miles to the north-east, Stonier(26) has shown that the rocks (presumably of the Woolomin Series) are in normal folds quite independently of the cleavage, which is parallel to that at Nundle. At present, however, there is no means of checking this assumed identity; the Swamp Oak rocks may be even a Permo-Carboniferous mass nipped in like those at Emmaville(27).

The thickness of the Woolomin Series is quite indefinite, and without doubt there is much repetition by faulting and folding. The presence of so many parallel jasper bands is evidence of this, but it would need a careful study, yard by yard, with much microscopical work, of the section from Warden's to Duncan's Creeks, to determine the horizons, and how often they are repeated. Even then the thickness will be unknown. There is no base, and the series is terminated by the fault of the serpentine-line.

(2). Bowling Alley Series.

This occupies the central portion of the map, and may be directly correlated with the Tamworth Series. It may be divided into five portions, the horizon of the limestone being taken as the line of reference, though it is true, that the limestone is not confined to one narrow zone.

The line of section at Bowling Alley Point, westward from Chrome Hill, is the most typical, and, on this, the subdivisions have been erected. Further north, the succession is less well known; further south, it is more disturbed, but, throughout, the limestone serves as a good horizon of reference for mapping.

(*a*).*Lower, Banded, Radiolarian Claystones.*—These occur next to the serpentine on Chrome Hill, one mile east of Nundle, may be traced thence up the west side of Munro's Creek, where they are much disturbed, and occur again south of Hanging Rock, in the small triangle of Bowling Alley rocks that lie east of the serpentine. In all three localities, the rocks are rather cherty.

Between Munro's Creek and Hanging Rock, the rocks west of the serpentine are more slatey, are more or less altered by the magmatic waters associated with serpentine-intrusion, and are greatly disturbed. Some cherty bands and spilites are present here. North of Bowling Alley Point, the same cherty claystones are developed, notably in the knoll that rises from among the Permo-Carboniferous rocks on the Peel River, but are less well marked north of the stream. Small lenses of limestone occur, but rarely. They have been seen on Munro's Creek, but have not yet been found to contain radiolaria. They are only a few inches in width. The maximum thickness of this series is about six hundred feet.

(*b*). The Lower Bowling Alley Tuffs and Breccias extend from Chrome Hill across the river to the limestones. Making due allowance for the numerous intrusions of dolerite (but none for possible strike-faulting), they seem to be about 4,000 feet thick. The rock is chiefly a grey-green, felspathic tuff, in which the constituent fragments are scarcely more than one-quarter of an inch in diameter, but occasionally it is more coarsely grained, becoming a regular breccia, with angular fragments of chert several inches in length. It consists chiefly of fragments of radiolarian chert, and finely divided igneous material, chiefly chips of spilite, and crystals of plagioclase, augite, and iron-ores; quartz is less frequent. The rocks are often extremely indurated, and, on weathering, the constituent fragments, or sometimes the cement, are brought out in high relief by natural etching.

Here and there, throughout the series, are subordinate layers of banded, cherty claystone. Flows of spilite are present, and, in particular, may be noticed the mass that forms the prominent crag, White Rock, that overlooks Munro's Creek (Plate xxiii.). Nevertheless the rock does not appear so abundant as in the upper series.

A hard, black, basalt-like band near the 'Possum Mine, Bowling Alley Point, has proved to be a peculiarly even-grained, basic tuff.

(*c*). The limestones form a series of long or short lenses, extending the whole length of the area (twelve miles). While

probably not all exactly on the same horizon, they are mostly confined to a narrow zone, while those apparently out of the zone, may, in some cases, be displaced by faulting, though this explanation will not hold for all. A brief description of several occurrences, commencing from the north, must now be given.

North of Black Jack, a red and white crystalline limestone occurs, and passing below the basalt cap, continues to the south. It forms two bands about 80 yards apart. On crossing Cope's Creek, it is thrown westwards by a small fault, but thence continues southwards, reaching a maximum thickness of over 50 yards, pinching out after about a mile. It is remarkable for its brecciated character, being composed of angular fragments of red, pink, and cream-coloured limestone, cemented with white calcite. It takes a high polish, and makes a handsome stone. Numerous crinoid-stems are present, but recognisable fossils are few.

At the east of the southern end of this, is a band, about 50 yards wide, of grey limestone much mixed with tuffaceous material and sediment. The patch is about half a mile long, and contains numerous, determinable fossils. About a mile to the south of this, is a pair of lenses of limestone, one of which forms a small bluff by the creek. It is of a brecciated character, and no determinable fossils were found. South again, and west of the general horizon, are two small lenses of grey, non fossiliferous rock, one on a hilltop north of Hyde's Creek, the other north of Cann's Plains Creek. It is hardly likely that they are faulted repetitions of the main horizon. One mile to the east of the last, are two fossiliferous lenses occurring in the saddle by the old Phœnix Mine. Half a mile east of these, is a small lens near the river, opposite Warden's Farm, with traces of fossils, which is probably on the same horizon as the fossiliferous rock by Tongue's house, on the river to the south. This is a coarse, tuffaceous breccia, with large fragments of limestone, one of which contains *Phillipsastræa.*

South of Cann's Plains Creek, and again on the general horizon, are situated the limestone quarries by Bowling Alley Point. It is a fairly pure, grey stone with a few fossils, about

30 feet thick, and enclosed between two layers of banded chert. On the hill, one-quarter of a mile east of this, is a second, more richly fossiliferous band, which, however, is rather silicified, and contains a good deal of tuffaceous material. This is inter-stratified with the tuffaceous breccias of the Lower Series. *Diphyphyllum*, *Heliolites*, *Heliophyllum*, and *Favosites* occur here. A little patch of white, saccharoidal limestone occurs in the bend of the river, opposite Pyrke's Store, to the east, again, of these.

Continuing southwards, there is a long series of small masses either of clear pure lens, or patches of tuffaceous breccia with large fragments of limestone; or, as these frequently are dissolved out, the limestone-horizon is represented by merely tuffaceous breccia, with large irregular cavities. The abundance of travertine, in the creeks draining from here, indicates the fate of the original limestone-content of these cavities. A small band of dark tuff, with limestone fragments, appears by the roadside south of Bowling Alley Point, the first limestone east of the river; and two other small patches lie about one mile to the south, on the hillside. In this case, the breccia is largely spilite. Near by, is a small lens of pure, grey limestone only a few feet wide. South, again, the limestone is present as fragments containing crinoid and coral remains, imbedded in a dark, compact spilite-lava, the microscopic examination of which gives every indication of rapid cooling. Skeleton-crystals of augite, of magnetite, and felspar are imbedded in a glassy matrix. There can be little doubt that here the organisms were killed out by a flow of spilite-lava, which caught up and included the individuals. The cavernous breccia and that containing limestone-fragments were doubtless produced by a rain of volcanic material falling on to calcareous organisms. Both indicate the very shallow water origin of the rocks concerned, as was pointed out in a previous note(14).

This cavernous and limestone-tuff breccia occurs again just north of Moonlight Hill, north of Swamp Creek. It is about 10 yards wide, and is bounded on either side by banded, cherty claystones. It occurs in the same manner on the sharp point north of the junction of Folly and Swamp Creeks. South of

Folly Creek, it is 100 feet thick. The lower portion is of the cavernous tuff-type, but the upper is a white crystalline limestone, with thin bands of quartz and tuffaceous material. It is followed by a narrow zone of fine breccia, covered by a great thickness of cherty claystones. About half a mile east of this, is a very narrow bar of pure, crystalline limestone.

Tracing further to the southwards, we find a small bar crossing the spur by the Swamp Creek Falls, and again a small patch, with *Diphyphyllum*, in the angle above the Falls. Both these approximate to the cavernous type. Nothing further is seen for two miles, then a tiny lens of cavernous rock is found on Ruzicka's Hill ("Risky's Hill") near Hanging Rock. This is east of the proper horizon. On the true horizon, a little limestone is to be seen at the head of Spring Gully, in Stringer's Tunnel (Deegan's lease), and, near here, some traces of brachiopods were found, in the slate, too obscured for determination *(fide* Mr. W. S. Dun). A few hundred yards further down hill, there is a small group of lenses by the Devil's Elbow, on the Hanging Rock Road, with obscure shells (one like *Atrypa*) and corals, including *Heliolites porosa*. One of these lenses is intruded by dolerite. A small lens occurs in Oakenville Creek, and ascends the hill opposite the cliffs of Hanging Rock. This is the southernmost occurrence noted. A complete list of the forms observed is given in the preceding Part. In the author's opinion, the limestone is not only analogous to the Tamworth limestone, but is on the same horizon.

(*d*). The Upper, Banded, Radiolarian claystones lie on these limestones. They form a well marked band about 1,000 feet thick. They may be traced from north of Cann's Plains Creek, across the Peel River, where they are well developed in Daylight and Mahoney's Creeks, and form the great cliffs that overhang the junction of Swamp Creek and Folly Creek. Here they are often very cherty. Further to the south, they cross Oakenville Creek, and are well developed near Mount Ephraim. They contain abundant radiolarian casts.

Interstratified with these, is a large amount of the tuff-breccia identical in character with that below the limestone.

The chief point of interest, in these rocks, is the abundance of the spilites. Their chief occurrences are shown on the map, but it should be noted that, as the nature of this rock and its peculiar interest were unknown to the author when the field-work was in progress (1909-10), less attention was paid to it than would otherwise have been the case. With this must be considered the very complex relation between the dolerites and the spilites, which adds further uncertainty to some of the observations. The occurrences mapped, however, have all been proved, by microscopic work, to be true spilite. North of Bowling Alley Point, the spilites are rare, but south of the township, a flow commences, which may be traced, with interruptions, right to the limit of the map. Commencing near the Peel River, it passes across the face of the hillside and forms the high point known as Tom Tiger, overlooking the mouth of Swamp Creek. Beyond, it runs across the face of Frenchman's Spur, where it is very fresh, and, after a break, widens out into the mass which forms the hill west of the Devil's Elbow, on the Hanging Rock Road. From here, it splits into two or more bands, one of which continues southwards to the head of Oakenville Creek, where it passes below the basalts, forming a ridge protruding into their lower portion. The splitting into several bands is probably the result of strike-faulting.

North of Tom Tiger, the mass is much disturbed with dolerite-intrusions, and veins of axinite with epidote-quartz and calcite, producing a rock closely resembling that described by Lacroix from Pic d'Arbizon, in the Pyrenees(28). This latter, he considers produced by the last stages of activity of an intrusive granite. It is difficult to see how this applies here. Unfortunately the occurrence was not thoroughly investigated in the field or laboratory. The axinite has been described, mineralogically, by Dr. Anderson(29).

A second and lower flow of spilite is that which forms the high, shutter-like wall in front of the Swamp Creek Falls, which have just broken through (Plate xxiv.). This flow, also, may be traced for some distance north and south. A third, possibly the uppermost horizon, occurs on the western slopes of Tom Tiger,

and may be traced northwards on to the roadway. This is of considerable width, the spilite being split into several layers, and intercalated with banded chert.

No evidence of pillow-structure has yet been seen among these rocks, but certainly it was not looked for specially.

(*e*). *Upper Bowling Alley Tuffs and Breccias.*—The Upper Tuffs and Breccias complete the Bowling Alley Series, and occur throughout, from north to south. They are about 3,300 feet in thickness, and are fairly free from intrusions of dolerite and flows of spilite. Interbedded with them, are minor bands of radiolarian clayshales; and probably the western limestone-lenses north of Cann's Plains and Hyde's Creek, belong also to this formation. All along its lower limit, occur those peculiar associations of tuff and clay-shales described by Professor David and Mr. Pittman from Tamworth(3), in which the tuff seems intrusive into the chert. The origin of this structure is not clear. The explanation of a somewhat similar feature at Lyndhurst, given by Mr. Pittman(30), does not seem to apply here. In a large measure, they may be due to crushing, for elsewhere brecciated cherts are found, that seem to have been almost telescoped, and the situation of the "tuff-intrusions," *i.e.*, at the boundary of tuff and chert, formations probably of very different powers of mechanical resistance to pressure, would be very favourable to such a crushing. But the same formation also occurs above the radiolarian chert, in the Baldwin Series exposed in Cobbadah Creek Gorge, where such crushing is out of the question. Moreover, the association seems to occur where tuffs lie on the claystones or chert, and has not been noticed in the reverse case.

It might be suggested, therefore, that were white-hot tuffaceous material to fall on wet mud forming in a shallow or partially dried lagoon, its heat might cause the mud to flake off and crack away, and the commotion produced by the escape of steam, from beneath, would give the stirring action necessary for mixing up the flakes of mudstone and the tuffaceous material. In support of this, it may be urged, that the flakes of mudstone are rarely more than a few inches long, and are often bent like dried cakes of mud;

that there is often a distinct alteration, a bleaching and induration of the mudstone at its contact with the tuff, and that it does not involve the action of a kind of steam-blast all along the line of contact of the claystone and tuff subsequent to their deposition, a process of which it is extremely difficult to conceive, or of which there is no evidence beyond the facts already mentioned. The absence of steam-cavities may be accounted for, on either hypothesis, by the crushing into the vacancy of the plastic tuff and shale, and the complete escape of the steam favours the new suggestion.

It should be noted that, if this explanation is true, either the mud must have been deposited in a very shallow sea, or the tuff must have fallen in such great quantity as to protect the lowest layers from immediate quenching by the seawater. There is little sign, apparently, of the tremendous disturbance that the latter alternative would necessarily have involved.

Above this, the breccias are seen to be interbedded with a considerable amount of banded claystone. The lower portion of this mass is best observed in the valley of Swamp Creek, the upper in the tributaries of Happy Valley, draining the Frenchman's Spur. Oakenville Creek also is in this series, for the most part. The breccias incline to be coarse, more so in the upper portions, and contain large fragments of banded chert. Occasionally they are so coarse-grained as to resemble the finer portions of the Baldwin Agglomerate, and possibly the narrow band of this rock, at the top of the Upper Tuff-breccias, may be considered the representative of the Baldwin Agglomerate in this neighbourhood. This does not, however, seem necessary.

In the upper portions of the series also, are bands of claystone containing *Lepidodendron australe,* radiolaria being found also in the fossil specimens. These occur on the main road, about one mile south of the Swamp Creek Bridge(G.L.,342).

Stratigraphy.—The five divisions of the Bowling Alley Series seem well substantiated; nevertheless, the great similarity of the Series below the limestones, to those above the limestones, is so suggestive of a wholesale repetition by strike-faulting (as is known

to occur further north), as to make it advisable to call attention to their differences. These are not very great. The spilites are present in much greater abundance, as far as is known, in the upper breccias than in the lower, a discordance in character that is significant only because the discussion is on the relationship of two adjacent series. High spilite-content is not a general characteristic of the Upper Series, for this lava is much less common in the series at Tamworth, which is considered identical with the Upper Bowling Alley Tuff-breccias and chert. Secondly, the peculiar coarse breccias, and large chert-fragments characteristic of the upper part of the Upper Breccias, are not at all common in the upper part of the Lower Breccias, nor has *Lepidodendron* been found yet among these.

It is very probable, however, that the whole belt of Bowling Alley rocks is traversed by a series of parallel, overthrust faults, so that what appears to be a single portion of the series, *e.g.*, the Lower Breccias, may be thickened by many repetitions. This would account for the very frequent interbedding of breccia and claystone throughout. Also the multiplication of spilite-flows might be explained thus.

The strike of these beds is generally parallel to that of the serpentine-line, and swings to the north and south direction sympathetically with the serpentine on Oakenville Creek, where a dip W.5N. at 70° has been observed. Generally speaking, the lower breccias and claystones have a very steep easterly dip (70°-90°), the limestones very little to one side or the other of the vertical, while the upper claystones and breccias have a slowly decreasing angle of dip to the west. Minor contortions occur here and there.

The chief difference throughout, between this series and the Tamworth beds with which they are correlated, lies in the apparent absence of the small lenses of radiolarian limestone. These are not very obvious in a rapid survey of the Tamworth region itself, and it is quite possible that they may occur in the Nundle region, but have been overlooked. Spilitic rocks are much more frequent, however, than at Tamworth.

3. The Nundle Series is quite analogous to the Barraba mudstones, with which they are correlated. It lies on the Bowling Alley Series, and in absolute conformity with it. It is very difficult indeed to draw any precise line of division, the formations shading one into the other. The lithological change lies in the replacement of the cherty claystone by a finely laminated, green-brown mudstone, with thin layers of yellowish felspathic material, which becomes the dominant rock of the formation. The igneous activity diminished, and is expressed by thick layers of a fine, even-grained tuff of the same mineral composition as the ground-mass of the coarse breccia, but is almost free from cherty fragments. Large and small lenses of blue, argillaceous, non-fossiliferous limestone are frequent. Here and there, conglomerate bands are present, and one well-marked zone can be traced from west of Yellow Rock Hill, across Nundle Sugarloaf (in front of Square Top), and north-west to Rodney Mountain, west of Bowling Point, beyond the limits of the map. The finer mudstones, in this series, contain radiolaria, and *Lepidodendron australe* is also present.

These beds dip to the south of west at angles gradually decreasing as one goes westward, though increasing again after some distance. Their thickness, measured along Jimmie's Creek to the summit of Square Top, is apparently 13,000 feet, but probably there is much repetition. The fault shown near Nundle, displacing the base of this formation, cannot be taken as proved, but is merely offered as a suggestion to account for the facts observed there.

4. The Dolerite.—This rock is present in very great amount, and its distribution calls for comment. It is chiefly in the Lower Radiolarian Claystones and Breccia, and the Upper Claystones, but is present, to only a very small extent, in the Upper Breccias. As far as the mapping goes, it appears to form large, irregular, sill-like intrusions, and has been traced throughout the series, from Hanging Rock to Black Jack. Time has not permitted their being mapped north of Hyde's Creek, though they are less common than to the south. They have been much disturbed; mining operations at the foot of Hanging Rock, and elsewhere, have shown that the country is full of "slides." Occasionally, as at Bowling Alley

Point, they contain very coarse pegmatitic veins of a composition similar to their own. Their relation to the spilite-lavas, in the field is often very perplexing; at times, they certainly intrude into the spilite, elsewhere the spilites appear to intrude into them. Sometimes, in hand-specimens, it is difficult to say which is which, the dolerite assuming a vesicular character. This was all the more confusing, as at the time of surveying, it was believed that the dolerite was subsequent to the peridotite(15), on account of the apparent intrusion of dolerite into peridotite, especially on the north slope of Chrome Hill. Work in the northern regions, and subsequent microscopic studies have shown this is not the case. The dolerite is related to the spilites, and is older than the ultra-basic rock. The mass of dolerite, in the peridotite alluded to, must have been torn off the adjacent dolerite-mass invaded by the peridotite. Petrological investigation shows that the rock has the structural characters of ordinary dolerite, except that the plagioclase varies from andesine, the usual type, to oligoclase albite in the Hanging Rock. Occasionally, specimens show a slightly gneissic flow-structure, notably some near Red Rock, which overlooks Munro's Creek (Plate xxiii.). This series of intrusions probably took place during, or shortly after, the deposition of the Bowling Alley Tuff-breccias, claystones, and spilite-flows. The abundance of dolerite, and absence of agglomerate, in this region, together with the abundance of agglomerate and rarity of dolerite in other regions, suggests that the same igneous activity might have had subterranean expression in the one case, superficial in the other.

5. Following the dolerite-intrusion, and deposition of the Nundle Series, there was a great earth-movement, a thrust from the E.N.E., which developed the persistent fault-plane separating the Woolomin and Bowling Alley Rocks. The peridotite was intruded into this plane during the movement. (The evidence for this statement will be discussed later.) Microscopic examination of the rocks proved them to be derived chiefly from hartzbergite, with a minor amount of herzolite and dunite. Generally the rock had a fairly even grain-size of about 2 mm., in diameter, but here and there, particularly on Chrome Hill by Bowling Alley Point, the

enstatite formed large plates several inches long, with poikilitically included olivine.

Associated with these peridotites, was a small amount of gabbro, which occurs chiefly on the top, and on the southern slope of Chrome Hill, on the western side of the peridotite. On the hilltop, it is very coarsely pegmatitic with large, grey-brown diallage, "saussuritised" felspar, and sometimes a little chromite. Large masses of chromite occur here with pseudophite, and coarse-grained rocks composed of chromite and smaragdite also occur, as well as rocks composed entirely of coarse bastite-crystals. The last two are rare. Down the slope, the rock is sometimes almost undecomposed, and the great basicity of the original felspar can be determined. A few instances of the prehnitic alteration of the felspars are also to be found.

One of the very few instances of serpentine occurring west of the great serpentine-line, is found on the Peel River, near Warden's homestead (Portion 9, Parish Dungowan). Only a few square yards are exposed in the river-bank, and alluvium covers the remainder, so that its relations are unknown. Probably it occupies a fault-plane, but, so far, the fault has not been sought on the hill across the river to the south, where it should occur if present.

The original peridotite has now been more or less completely altered, and it is the variety and sequence of these changes that gives this locality its unique interest. The subject will be fully discussed from a petrographical standpoint later; at present, merely the field-facts will be stated.

(*a*) *Mechanical Alteration.*—This consists in converting the rock into the well-known schistose material. It may be either complete or partial, in which case large or small nodules of massive serpentine remain imbedded in the sheared mass. This process has naturally taken place, to the greatest extent, on either side of the intrusion, but particularly on the eastern. Thick schistose bands have a massive central core.

(*b*) *Chemical Alteration.*—This may be considered as: (1) hydration (serpentinisation); (2) carbonation; (3) silicification; (4) leaching. The last three are more or less related together.

(1) Hydration has taken place, to a greater or less extent, throughout the whole mass; very little olivine remains unattacked. We, therefore, get normal, massive, bastite-serpentines, schistose serpentine, and antigorite-serpentine, the latter being best developed on the Razorback Ridge, half-way up Munro's Creek, where some of its features resemble Weinschenk's stubachite(31).

(2) Carbonation is developed best between Folly Creek and Quackanacka Creek, and is well exposed in the workings of the Trevena gold-mine. The rock is more or less completely converted into carbonates of magnesia and iron, with a little talc, quartz, chalcedony, etc. With this is associated more or less pyrites. Both the schistose and massive types of serpentine have been thus altered, and their original structures are well preserved. The rock does not make a strong outcrop, but, on the surface, is weathered to a cavernous, red hæmatite, with a little talc, by which the formation may be traced. In the western side of the serpentine, the Bowling Alley rocks have been acted upon by the same agents as transformed the serpentine. Clayshales, spilites, and tuffs occur highly oxidised and carbonated, and impregnated with pyrites. This entire formation is more or less auriferous, but differs entirely from any other gold-bearing formation in the district.

(3) Silicification takes the form of replacement of the serpentine by chalcedony, quartz, and opal. The change occurs in various ways, and frequently is associated with leaching. In Sheep Station Creek, the serpentine contains little cavities lined with chalcedony, and the main mass of the rock is partly replaced by silica, as chalcedony and white opal. On Cope's Creek, and to the east of Chrome Hill, is a narrow band of serpentine, changed chiefly to very finely divided chalcedony, with the preservation of the schistose structure of the original rock. Between Munro's Creek and Folly Creek, the serpentine is replaced by a bottle-green opal with black cloudy masses (pyrolusite). This opal forms kernels surrounded by a husk of hæmatite, veined with white opal, and speckled with dusty talc or hydromagnesite. By Hanging Rock, at the head of Oakenville Creek, on the east side of the serpentine, is a large mass of silicified rock, from which excellent specimens of

chalcedony may be obtained, together with botryoidal masses of magnesite. Here, too, the rocks may be thoroughly leached, and left as a siliceous sinter, more or less filled with hæmatite. This was described by Wilkinson, in 1885, as due to geyser-action(25). While this is by no means probable in the strict sense, it is certainly the effect of ascending, hot, siliceous solutions.

The date at which the great silicification of the Woolomin Series took place, is as yet uncertain. Probably it was during the orogenic period. Huge quartz-veins were formed through the Woolomin rocks, and to a much less extent in the Bowling Alley Series, while they are absent from the Nundle beds. While these veins are found in the dolerite (with epidote), the granites and porphyries are quite subsequent to them.

6. Granodiorites, Granites, and Porphyries.—There is no direct evidence as to the relative age of these rocks and the Permo-Carboniferous, but owing to the want of metamorphism in the latter, and the slight resemblance between the granites, etc., and the oldest types described by Mr. Andrews as Carboniferous, the Nundle rocks are tentatively classed as of that age. As will be seen, the granite probably underlies the greater portion of the area at no very great depth. The largest exposure is on Duncan's Creek, and is eight or ten square miles in area. Its composition has not been thoroughly investigated. Some variation was noted in the field; the specimen collected proved to be granodiorite, orthoclase being subordinate to plagioclase. It was noted that the upper surface of the mass had only a slight inclination, as along the stream-scared, western slopes, the boundary of the granite swung back and forth in sympathy with the contour-lines. All around the boundary is an immense number of intrusions of porphyry of several types, a dark blue fine-grained rock with white felspar and black hornblende-crystals, being most abundant. About fifty of these have been mapped, but there are many more, particularly just above the granite-boundary on the steep slope above-mentioned. The long, northern point of the massif passes into this rock, and intrusions of the porphyry, into the granodiorite itself, have been noted further to the south, below Yerro-

winn. The intrusions are noteworthy in that they are roughly oval in shape rather than in definite dykes, indeed, few, narrow, lengthy dykes have been observed. Naturally the intrusions are less abundant at a distance from the granodiorite. A remarkable increase in the number of intrusions, on Frenchman's Spur, may be taken as evidence of approach of the underlying batholith towards the surface in that neighbourhood. An intrusion of porphyry into dolerite, near Moonlight Hill, is perhaps worthy of mention.

Granite occurs again at Mount Ephraim, and may be traced thence towards Yellow Rock Hill. The complicated geology of this portion has not yet been mapped. In these rocks, orthoclase is present in greater amount, and the rock is strictly a granite.

Lastly, there is a mass of porphyry intruding the Nundle mudstones, near the head of Jimmie's Creek, and a few small dykes have been noted between this and the river. These are all very decomposed, so much so that one sill-like intrusion of porphyry, on the main road, is locally termed sandstone.

There are also rarely dykes of odinite and vosgesite, which occur on Frenchman's Spur, and in Daylight Creek Gully. It is very possible that these are differentiates of the granodiorite magma.

Mention may here be made of a neck of light grey andesite about 30 yards in diameter, by Oakenville Creek, on the south side of Hanging Rock. Its appearance suggests that it is of some considerable age, and the acidity of the plagioclase is perhaps sufficient to place it in the keratophyres, in which case it may be comagmatic with the Devonian spilites.

(7). Permo-Carboniferous.—In 1891, Stonier(69) recorded the occurrence of *Glossopteris* in shales met with in a shaft sunk on Anderson's Flat, which is the area by the river, stretching from Sheep Station Creek northwards. Recently, Mr. Tooth, the local schoolmaster, drew the writer's attention to the occurrence of fossils resembling those of the Permo-Carboniferous, revealed in digging some fence-post holes at Reichel's homestead, on Portions 11 and 144, at the northern end of Anderson's Flat. All the material available was searched, and Mr. Tooth's discovery was fully confirmed. The rock is an impure sandstone, and contained *Deltopec-*

ten, Martiniopsis, and obscure casts resembling *Astartila, Edmondia, Mourlonia* and *Ptycomphalina.* It is impossible to fix the horizon of these, but they are more probably of Upper than Lower Marine Age, with portion of the upper freshwater measures.

The rocks do not make any good outcrop, and accordingly the boundaries drawn, rest entirely upon the change of surface-slope. At Reichel's, the fossils were found in the low saddle between two hills of Bowling Alley rocks, but the wide opening of the river-valley at this point, both on the eastern and the western side, is a marked and unique feature, which may be due to the differential erosion of the soft shales and sandstone from among the harder Devonian rocks. In that case, it is probable that Permo-Carboniferous rocks lie beneath most of the widespread alluvial covering of the valley-floor.

The rocks are doubtless portions of a great overspreading sheet of Permo-Carboniferous rocks, and were preserved by down-faulting probably during the early Mesozoic period of tectonic movement. As they lie more than 40 miles from the nearest known masses of Permo-Carboniferous rock, it will be seen how great an extension of the area of Permo-Carboniferous sedimentation is indicated by them.

(8) Tertiary Gravels and Clays.—These lie beneath the basalt-masses, and are most easily described with a locality-grouping.

The Yerrowinn Gravels are exposed on the south side of Duncan's Creek, where they are about 120 feet thick. They are here composed of coarse gravel. On Folly Creek, to the west, they are much thinner, about 20 feet in all, and may be traced thence on to the watershed between Munro's and Folly Creeks. Here they are also gravels, but finer sandy bands have been found with leaf-impressions. Some beautifully preserved, coniferous wood occurs in these gravels, similar to that found near Barraba. The slope is to the west, with a fall of 210 feet in $2\frac{1}{2}$ miles. The boulders consist of reef quartz-jasper, with granite and phyllite.

In the basalt, about 200 feet above the top of this gravel, there is a small, narrow band of gravel at the eastern face, and a third horizon is suspected still higher up. Near the head of Duncan's

Creek is a gravelly deposit in the creek-bed, which contains large zircons, colourless or brown, and sapphires, sometimes of good quality, "as large as your finger-nail and blue like a castor-oil bottle." These are probably derived from another interbasaltic layer of gravels.

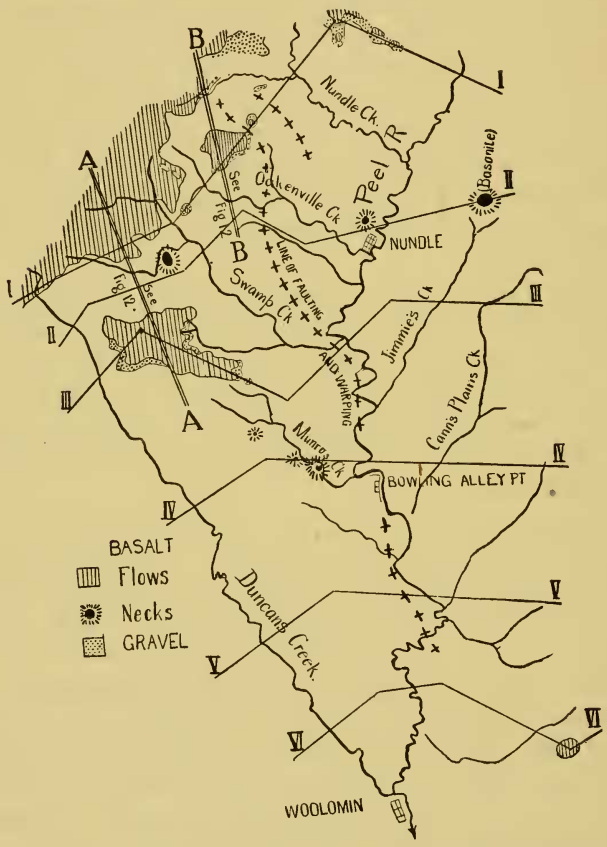

Fig. 3.—Plan of the Nundle District, showing position of basalt necks and the various lines of section in Figs. 4 and 6.

On the divide, between Nuggety and Quackanacka Creeks, a peculiar, fine, pink clay lies beneath the basalt. It has not been

proved to contain fossils. Possibly these are the clays which Wilkinson describes as being under "the Sugarloaf," but as that name is applied to every hill in the vicinity, one cannot be certain.

The Mount Sheba Series is, perhaps, the most continuous and important, as being the most largely worked for gold. They occur under a thin capping of basalt, at the head of Oakenville Creek, where they are largely mixed with clay and sand. Just below the basalt in Dangar's Gully, a southern tributary of Oakenville Creek, a tunnel has been driven in soft, carbonaceous shales partially baked by the basalt. These are full of plant-impressions. Across the valley, a small face of gravel is exposed in the Mount Pleasant workings (more usually known as Mount Misery, the name having been altered since the abandonment of the mine in winter time). Here the gravel is about 80 feet thick, and not very coarse, with

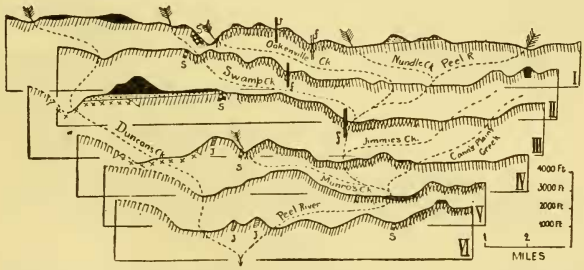

Fig.4.—Cross-section through Nundle District to illustrate relation of physiography to geological structure.

clay and sand, and leaf-impressions in limonite. The gravels continue below the basalt, were opened up at Deep Lead Creek, half a mile to the west, and a huge face has been sluiced away at the head of Butcher's Gully, the Red Hill Workings. Here, the gravels, fine, coarse and sandy, are about 100 feet in thickness. A fault of 200 feet throw (approximately) separates Mount Sheba from this. It lies to the west again, and has a similar, huge, sluiced face. A smaller sluicing occurs on the southern side of the same patch of gravel.

The occurrence at Mount Ephraim, south of the Sheba Sugarloaf, is peculiar, and needs further investigation before a descrip-

tion can be given. Perhaps it has been disturbed by the fault that separated Red Hill from Mount Sheba. Moreover, the gravels lie on granite. As might be expected, there is a very large amount of decomposition always taking place in the rocks on which the gravels lie, and the non-removal of such decomposed material leads to peculiar appearances. Granite is peculiarly unstable ("la maladie du granite"), and the result here is very remarkable.

Between here and Nundle Creek is a run of granite and shale, overlain here and there with basalt; but the country was so confused, and the trees so thick, that about a mile of it has been left unmapped. A very wide area of hard gravel occurs east of Nundle Creek, while a few yards of gravel and a little basalt occur about half a mile to the north of that.

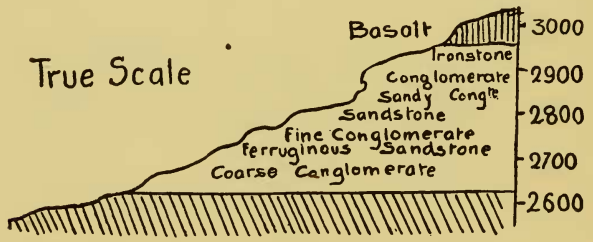

Fig. 5.

Yellow Rock Hill is the thickest mass of gravel in the district, being 340 feet thick at the northern end. Fig. 5 is a true scale section of this face. It thins out to about 40 feet only, and though the west base of the gravel is 140 feet higher than the eastern; the western base of the overlying basalt is lower than the east. The gravel contains reef-quartz, red jasper, and Bowling Alley breccia together with silicified wood. Soft, current-bedded bands of argillaceous sandstone are intercalated, but rarely.

Indications of continuances of this lead to the south, up Nundle Creek, and to the south-west across the Peel River, have been noted, but not investigated. The latter was probably the main-stream line. Wilkinson says it may be traced west in the direction of Quirindi(25).

All the material collected was submitted to Mr. Henry Deane, F.L.S. He recognised fragments suggesting the *Cinnamomum*-type, *Sterculia, Flindersia, Clerodendron tomentosum,* and *Ficus scabra.* There are no leaves which can be referred to *Eucalyptus.* He adds: "I do not think these fossil leaves can lead to any deductions as to age. They are quite of the same character as the Brush-vegetation of our coast, a type which has existed in Eastern Australia from the Miocene, if not from an earlier period. Of course, the climate must have been a much moister one, owing partly to the absence of a parched interior, enabling a luxuriant vegetation, now restricted to patches of the coast, to spread over the tableland and down the western slopes."

Comparing the above facts of the mode of occurrence of the gravels, their displacement by faulting, the abundance of leaves, and the presence of seeds, as noted by Wilkinson, with the criteria given by Andrews(**32**), it is evident that the Nundle leads must be classed with the newer Series, and are consequently of Pliocene age.

(9). Tertiary Volcanic Rocks.

(*a*) *The basaltic series.*—As stated above, these occur capping the gravels that had been deposited in immature valleys. They overflowed the brims of these valleys and flooded the low, rolling country between them, which, however, was not completely planated, so that the resistant rocks still formed elevations that rose some distance into the basalt, or remained as islands above the lava-flood. We may note the irregularities produced by the resistant spilite behind Mount Sheba, the serpentine-ridges by Hanging Rock, and the inlier of Woolomin rocks at the head of Swamp Creek. Apart from the irregularities, the general, slight discordance between the boundary of the basalt and the contour-line on the plateau, shows the mature character of the prebasaltic surface, trenched, as it was, by immature valleys. This is evidence towards the substantiation of the process of peneplanation, uplift, and partial dissection claimed by Andrews to have taken place before

the eruption of the older basalts, and which was repeated on a grander scale, before the Newer Basaltic Period. (Fig.6).

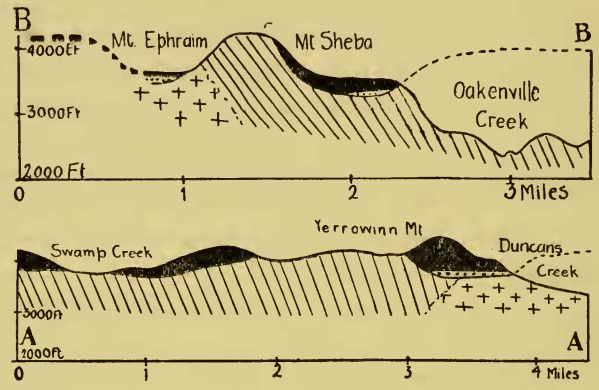

Fig.6.

The manner of eruption of the basalt is unexpected, while, in general, the mode of occurrence is that of plateau-basalts derived from fissure-eruptions, as stated by Mr. Harker(33). No fissures (dykes) can be found, except a small one in a fault-plane crossing Jimmie's Creek, and one, 10 yards wide, intruding the dolerite north of Ruzicka's Hill. On the other hand, at least six basalt-necks have been found as follows(Fig. 3) :—

(1)Donald's Mount at Nundle, a hill chiefly of basalt intruding into the slates (about 120 × 170 yards in area).

(2)Nuggety Sugarloaf, south of Nuggety Creek, a steep hill 500 feet high, the southern side of which is basalt, about 500 × 400 yards in area.

(3)A circular patch of basalt, about 30 yards in diameter, on the ridge east of Munro's Creek.

(4), (5), and (6). The patches of basalt in the valley of Munro's Creek, near the Razorback, respectively 160 × 120, 50 × 50, and 20 × 20 yards in approximate area. The last is strongly prismatic, and makes a small hillock overlooking the tributary creek at this point.

Whether the basalt on Black Jack (about 100 acres in area) is part of a flow from a distant vent, or surrounds a local pipe, cannot yet be stated.

Three types of basalt are developed. There is a smooth, aphanitic type, which has a grey surface on weathering, streaked with etched-out flow-lines; and there is also a darker, not so very finely grained type, with a rough hackly surface, and a habit of breaking into small pellets when rather decomposed. An intermediate variety is the commonest rock, and is frequently prismatic, but the extreme types sometimes occur interbanded in the same mass, either in the necks or in the basalt-flows.

A third type is thoroughly scoriaceous and largely decomposed. This occurs in a flow extending north and south of the Dams on Burnt Hut Creek, by Hanging Rock. No basalt-tuffs or breccias have yet been found in the necks or between the lava-flows.

(*b*) Nepheline-basanite occurs, forming the upper 300 feet of Square Top Hill, two miles west of Nundle. This has been shown (24) to be a member of a varied series of rocks of a basic alkaline character, that occur intruding into the Tertiary basalts. The series includes coarsely granular theralites and teschenites, nepheline-basanites, and coarse dolerites with large purple augites, with or without analcite. The mode of occurrence of the Square Top rock is as yet uncertain.

A small amount of vesicular olivine-basalt has been found around the base of the basanite, and it has been noted that the lower portion of the latter is coarser-grained, and richer in augite-phenocrysts than the upper portion. No gravel was found below the basalt, but only the eastern face has been studied as yet. Probably, as elsewhere, this was a sill-like intrusion through a basalt-flow, possibly it was a mass of the mamelon-type.

Rocks of this alkaline group occur in great amount, as boulders in the Peel River, evidently derived from the Liverpool Range. They appear to occur *in situ* on Wombramurra Creek, and it is probable that the very striking cone, Wombramurra Peak, is of this character, to be correlated with Mount Warrawalong, near

Newcastle(24), and Delungra Peak, near Warialda(27), which it strongly resembles in appearance.

Some peculiar chloritised dolerites, with large purple augites, occurring in the basalt-range east of Mount Ephraim, are probably sills related to these alkaline rocks. They have not yet been investigated.

(10). Pleistocene and Recent Alluvial Deposits.

Two series of alluvial deposits occur along the Peel River and Duncan's Creek. The higher deposits are frequently auriferous, and have been worked on the Peel River, south of Bowling Alley Point, and at Bowling Alley Point itself. A well marked terrace, about 50 feet high, occurs on the east bank of the Peel River, one mile north of Nundle.

Recent alluvial deposits occur all along the river and its larger tributaries, and form an area of over a square mile in extent at the township of Woolomin. They are often auriferous, but rarely very deep. The streams entering the Peel River, on the western side, usually break up into distributaries, and soak through wide marshy tracts into the main river. Hyde's Creek and Cope's Creek are conspicuous examples of this.

Economic Notes.

Gold was first found in this district in 1852, and, since then, about £900,000 worth has been obtained.* It occurs in many ways:—

(*a*) In quartz-veins near the boundaries of the dolerite, which have generally suffered much faulting.

(*b*) In quartz-veins in the slate, away from the dolerite.

(*c*) As impregnations in pyritous, carbonated serpentine.

(*d*) As pyritous impregnations in claystone, spilite, etc., in wide, low-grade channels with rich quartz-stringers. These are the

* A very remarkable theory of the origin of this gold, was put forward by the Rev. W. B. Clarke in 1853(2), in a lengthy report on the subject. It was considered to be deposited under a shallow sea in the vicinity of volcanic eruptions.

deposits that occur beside the carbonated serpentine, and are the result of the same agencies of change. The gold is chiefly partly free, but largely in the pyrites. ("Battery test" on separated pyrites, 20oz., 15dwt. per ton, according to local report).

(*e*) In Tertiary drift mined by hydraulic sluicing, from the Sheba and Mount Ephraim gravels.

(*f*) In high-level river-gravels (sluiced).

(*g*) In the present river-gravels, won by dredging.

Scheelite occurs in small quantities in most of the above modes of occurrence, but of these, only the first two have yielded payable amounts. It forms lenticular bunches in claystones, associated with a little quartz. Stibnite occurs near Nundle, in a brecciated fissure-vein in clayshales. Chromite forms large segregations in the serpentine, particularly on Chrome Hill, behind Bowling Alley Point.

The white marble does not form large enough masses, and is too difficult of access for economical working; the red marble is in greater quantity, takes a good polish, and is easy of access. Zircons and sapphires have been found in interbasaltic gravels, but are rarely of good quality.

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EXPLANATION OF PLATES XXII.-XXIV.

Plate xxii.

Geological Map of the Nundle District.

Plate xxiii.

View looking up Munro's Creek, showing the serpentine-belt to the left, the cliffs of spilite, "White Rock," in the centre, and the dolerite cliffs, "Red Rock," to the right.

Plate xxiv.

Swamp Creek Falls, dropping behind a shutter-like mass of spilite.